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ELECTRIC POWER SUPPLIES REQUIRED FOR ION PROPULSION: PRINCIPAL CHARACTERISTICS

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ELECTRIC POWER SUPPLIES REQUIRED FOR ION PROPULSION: PRINCIPAL CHARACTERISTICS

C. Landrault*, P. Luquet** and M. Briot

ABSTRACT. Based on a bibliographic survey the main ion thrustors are reviewed. The different electric power supplies and their characteristics are discussed. A project of microthrustors designed for CNES is presented.

INTRODUCTION /3***

Energy conversion aboard space vehicles is an important problem whatever the mission considered.

Indeed, this energy, whether stored in chemical or nuclear form or collected from solar radiation, must be conducted to the point of use in the form of electrical energy at a given voltage.

In this report, we are more particularly interested in the system for supplying the electrical energy of ion micropropulsors for the two ionization processes:

— contact ionization;

— ionization by bombardment.

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***Numbers in the margin indicate pagination in the original foreign text.

In the first part of this report, we briefly review the operational principle of different types of ion propulsors.

In the second part, we examine the different power supplies of electrical energy necessary for their operation.

The determination of the characteristics of these supplies is the subject of the third and fourth parts.

In the conclusion to this study, we have taken the example of a single-strip propulsor with contact-ionization of cesium and electrostatic beam deflection, the performance of which has been defined by the Direction of Programs and Planning of the National Center for Space Studies.

I. ION PROPULSION

I-1. Principle of Operating and Obtaining Thrust [1] [2]

The thrust is obtained by the ejection at a very high velocity (40,000 to 50,000 m/sec) of positive ions created from atoms of the propellant (generally Cs or Hg). An ion propulsor is thus composed of three sub-assemblies (Figure 1.1).

I-1-1. Production of Ions at Working Potential /4

The propellant goes from the reservoir to the vaporizer and to the valve through a capillary tube. The propellant vapor, at a pressure of several torr, is then ionized. The different ionization processes used are discussed in paragraph I-2.

I-1-2. Acceleration of Ions and Deflection of Their Trajectory

The ions emitted by the ionizer are accelerated by an electrostatic field. The ionizer is in fact maintained at a higher potential than a

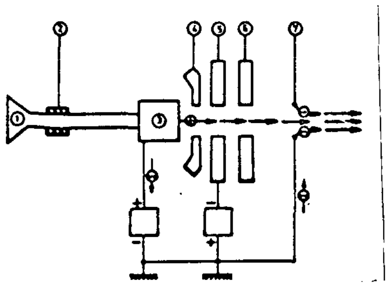

Figure 1.1. Principle of ion-propulsor operation:

1 - reservoir; 2 - vaporizer and valve; 3 - ionizer; 4 - focusing electrode; 5 - accelerating electrode; 6 - decelerating electrode; 7 - neutralizer.

reference potential (the satellite), and the accelerating electrode is held at a potential below this reference. This electrode can be of two types, as shown in Figure 1.2, for the case of contact ionization of cesium.

Superposition of a differential voltage on the accelerating electrodes permits the thrust vector to be directed. This result can also be obtained by applying a differential voltage to the decelerating electrodes.

I-1-3. Neutralization of the Beam at Exhaust

In order to cancel the charge on the satellite, as well as the space charge of the beam, it is necessary to neutralize the beam. This neutralization is obtained by injection of electrons. The different neutralization methods are discussed in paragraph I-3.

I-2. Ionization Methods

Ionization of the propellant in gaseous form is obtained by two methods at present:

— contact ionization;

— bombardment ionization.

I-2-1. Contact Ionization /5

The diagram of Figure 1.3 gives the principle of an ion propulsor with contact ionization.

Single-button propulsor (electrostatic beam deflection toward A, A', B, or B')

Single-strip propulsor (electrostatic beam deflection toward A or A')

Figure 1.2. Accelerating electrode.

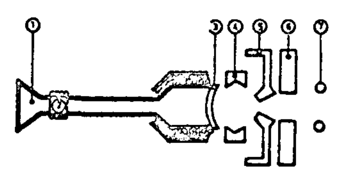

Figure 1.3. Propulsor with contact ionization:

1 - propellant reservoir; 2 - vaporizer and propellant-flow valve; 3 - porous tungsten ionizer; 4 - focusing electrode; 5 - accelerating electrode; 6 - decelerating electrode; 7 - neutralizing filament.

The propellant vapor passes through an ionizer made of a refractory material held at high temperature. The refractory material is chosen so that its emission potential is higher than the first ionization potential of the propellant.

If cesium, whose first ionization potential is 3.87 V, is used as the propellant, the best refractory material is tungsten, whose emission potential is 4.1 V.

I-2-2. Ionization by Electron Bombardment

The diagram of Figure 1.4 shows the principle of a propulsor with electron bombardment.

The vaporized propellant enters a cylindrical chamber, where it is ionized by electron bombardment. The bombarding electrons are supplied by a cathode; they are accelerated by an electrostatic field and attracted by a cylindrical anode generally placed on the periphery of the chamber. The electrostatic field between the cathode and the anode must be such that the electron energy is higher than the first ionization potential of the propellant used (10.58 V for mercury, 3.87 V for cesium).

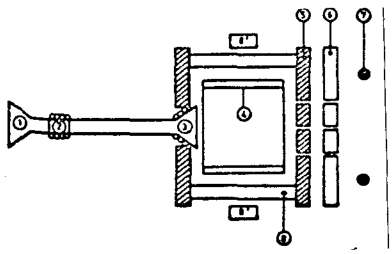

Figure 1.4. Diagram of the principle of a propulsor with bombardment ionization:

1 - propellant reservoir; 2 - flow valve and propellant vaporizer; 3 - cathode; 4 - anode (cylindrical); 5 - screen grid; 6 - accelerating grid; 7 - neutralizer; 8 - permanent magnet (cylindrical) or solenoid.

Improvement in ionization efficiency is obtained:

— by superposing an axial magnetic field on the electrostatic field (increasing the electron paths);

— by holding the walls of the chamber at a potential identical to that of the negative tip of the cathode, to repel the electrons in the chamber.

The ejection portion of the chamber is made of a screen which allows passage of the ions. The remaining ions recombine with electrons near the walls.

I-3. Neutralization Methods /6

I-3-1. Neutralization by Filament

Electrons are obtained from a hot filament. This method is applicable only to micropropulsors of low thrust because of the limited filament life.

I-3-2. Neutralization by "Plasma Bridge"

This method uses a source which emits a beam of electrons and neutral atoms. The neutral atoms are ionized by the electrons and thus form a plasma bridge between the electron-emitting source and the ion beam. The electrons are emitted by a heated cathode, and the neutral atoms come from the vaporized propellant (mercury or cesium).

II. DIFFERENT VOLTAGES REQUIRED

Analysis of the operation of ion-micropropulsors has shown that a certain number of power supplies, both AC and DC, are required. We shall list them, and their characteristics and their constraints will be given in Chapters III and IV, respectively.

II-1. Propulsor with Contact Ionization

Figure 2.1 gives the distribution of different voltages required for the operation of the micropropulsor.

On retracing step by step the description of operation made in Section I-2-1, the following power supplies appear:

II-1-1. Power Supply 1 (V_1)

AC supply for the vaporizer heater.

II-1-2. Power Supply 2 (V_2)

AC supply for heating the refractory material of the ionizer.

II-1-3. Power Supply 3 (V_3)

Holds the reservoir, vaporizer, capillary tube, ionizer, and focusing electrode at high positive potential. /7

Note: Holding the reservoir at a high positive potential can present certain problems when the reservoir is common to several propulsors. Various technological solutions have been developed for this problem [3]. These solutions have been discussed at the meeting on Studies of Ion Propulsion held on 25 and 26 June, 1970, at Toulouse.

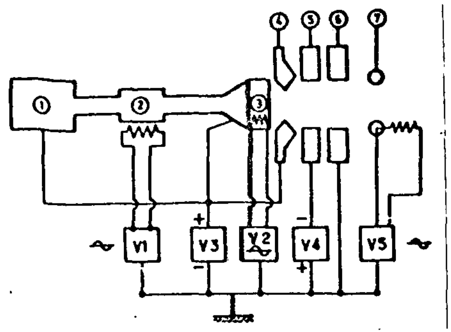

Figure 2.1. Power distribution for a micropropulsor with contact ionization.

1 - propellant reservoir; 2 - valve and vaporizer; 3 - ionizer; 4 - focusing electrode; 5 - accelerating electrode; 6 - decelerating electrode; 7 - neutralizer filament.

II-1-4. Power Supply 4 (V_4)

Holds the accelerating anode at high negative potential.

II-1-5. Power Supply 5 (V_5)

AC power supply to the neutralizer for electron emission.

II-1-6. Power Supply 6 (V_6)

It does not appear in the operating principles; it supplies the control logic.

II-1-7. Power Supply 7 (V_7)

Controllable DC supply required for beam deflection.

II-2. Propulsor with Bombardment Ionization

Figure 2.2 gives the distribution of different voltages required for this type of micropropulsor.

Following the same pattern as in the preceding Section, the operating description of Section I-2-2 shows these power supplies:

II-2-1. Power Supply 1 (V_1) /8

AC supply to the vaporizer.

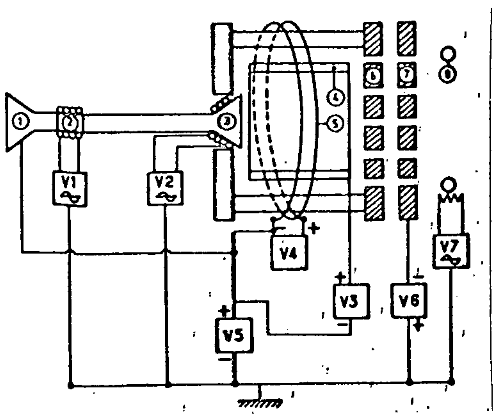

Figure 2.2. Power distribution for a micropropulsor with bombardment ionization.

1 - propellant reservoir; 2 - valve and propellant vaporizer; 3 - cathode; 4 - anode (cylindrical); 5 - solenoid; 6 - screen grid; 7 - accelerating electrode; 8 - neutralizer filament.

II-2-2. Power Supply 2 (V_2)

Power supply for cathode heating.

II-2-3. Power Supply 3 (V_3)

DC supply to the anode.

II-2-4. Power Supply 4 (V_4)

Power supply required for creating the magnetic field, unless permanent magnets are used.

II-2-5. Power Supply 5 (V_5)

Holds the propellant supply and ionization chamber at high positive voltage.

II-2-6. Power Supply 6 (V_6)

Holds the accelerating electrode at high negative voltage.

II-2-7. Power Supply 7 (V_7)

AC supply to the neutralizer.

II-2-8. Power Supply 8 (V_8)

As in the micropropulsor with contact ionization, this supply feeds the control logic.

II-2-9. Power Supply 9 (V_9)

Controllable DC supply for beam deflection.

The power supplies needed for the operation of the micropropulsor are reviewed in Table I.

TABLE I /9

	Type	Contact ionization	Bombardment ionization
Vaporizer	AC	x	x
Ionizer heating	AC	x	
Cathode heating	AC		x
Positive high voltage	DC	x	x
Negative high voltage	DC	x	x
Neutralizer heating	AC	x	x
Solenoid (optional)	DC		x
Anode	DC		x
Control logic	DC	x	x
Deflection	controllable DC	x	x

III. VOLTAGE-CURRENT CHARACTERISTICS OF POWER SUPPLIES [4 - 12]

For each power supply, we are going to determine the current and the voltage necessary for the operation of the micropropulsor. The constraints needed for their definition will be given in Chapter IV. /10

Bibliographic studies have been made on the three types of micropropulsor listed in Table II.

TABLE II

Type	Propellant	Ionization method	Optics
Sert II	Mercury	Bombardment	Multi-button
H. R. L.	Cesium	Contact	Single-strip
E. O. S.	Cesium	Contact	Single-button

H. R. L.: Hughes Research Laboratories;
E. O. S.: Electro-Optical Systems.

III-1. Alternating-Current Power Supplies

The experimental curves of Figure 3.1 give the different AC powers as functions of the ratio of the thrust to the specific impulse [13].

III-1-1. Vaporizer Heating

This power supply requires a DC-AC converter for which we shall give the output characteristics in Table III.

TABLE III

Type	V_{volts}	I_{amps}	P_{watts}	$Thrust_{mN}$
Sert II	1.78	1.7	3	30
H. R. L.	5	1.3	6.5	2.5
E. O. S.	3.5	1.3	4.6	0.1

The differences between these powers and those obtained from the preceding curve are explained as follows: /11

— they use different technologies;

— the propellants used have different boiling points.

It is the same for the differences which appear in this table.

In conclusion, one can state that the power required for the vaporizer is on the order of a few watts.

Furthermore, a compromise must be made between the response time of the system and the power required.

This is clearly shown by the following two micropropulsors which resulted from the same request for proposals:

— that studied by Electro-Optical Systems, Inc. (see Table III), where only a relatively low vaporizer power has been considered, which can be obtained by the most suitable technology (smaller capillary tubing in the propellant feed, for example).

— that studied by Hughes Research Laboratories, which for the same thrust level (0.1 mN) requires a distinctly higher vaporizer power. This is explained by the fact that this design avoids too great a penalty in response time.

III-1-2. Ionizer Heating

II-1-2-1. Heating of Refractory Material (Contact Ionization) /12

The data given in Table IV show that the power required for a micropropulsor with 0.1 mN thrust is on the order of ten watts. For higher thrusts, the power required will be increased, since the ionizer surface will be greater.

TABLE IV

Type	V_{volts}	I_{amps}	P_{watts}	$Thrust_{mN}$
H. R. L.	10	5.7	57	2.5
E. O. S.	4.4	2.3	10.1	0.1

This power is a function of the technology employed and of the performances sought for the response time. It represents about 40% of the total power required for propulsor operation.

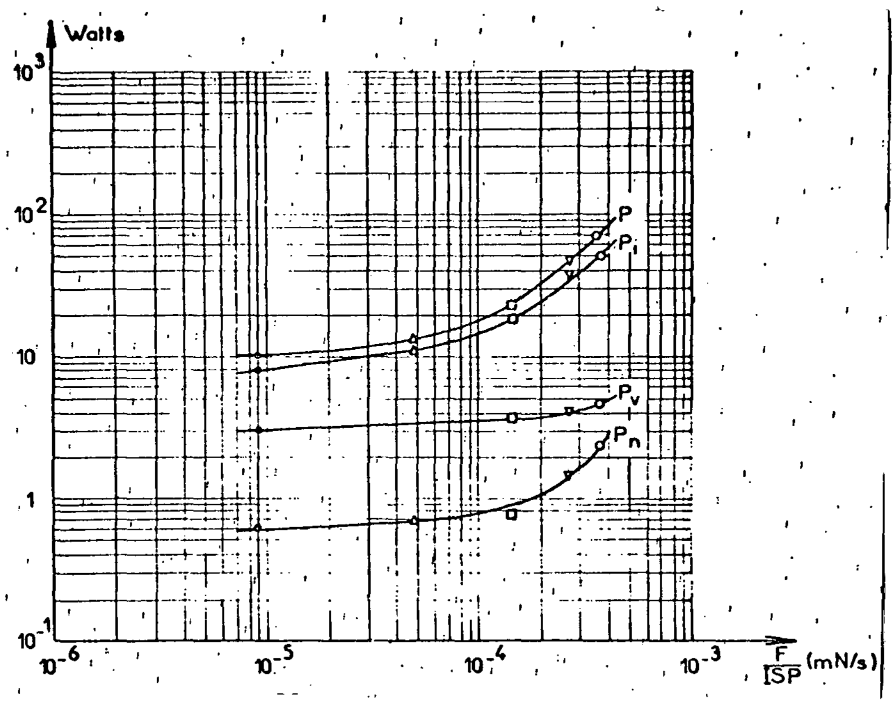

Figure 3.1. The symbols on the graphs refer to microprolusors with the following thrusts:

O - 0.06 mN; Δ - 0.2 mN; - 0.4 mN; ∇ - 1.3 mN; O - 2 mN.

III-1-2-2. Heating of Cathode (Bombardment Ionization)

Based on the operating principle of a micropropulsor using electron bombardment, the power required is a function of the electron current emitted by the cathode.

A DC-AC converter is needed; its characteristics for the previously-discussed micropropulsor with bombardment ionization are given in Table V.

TABLE V

Type	V volts	I amps	P watts	Thrust mN
Sert II	5.2	1.5	7.8	30

The output power of the converter is essentially a function of the technology employed. Thus, for Sert I, where the power level was analogous to that of Sert II, power on the order of 200 watts was required. A more comprehensive technological study has led to a considerable decrease in this power for Sert II, as shown in Table V. /13

III-1-3. Neutralizer Heating.

III-1-3-1. Neutralization by Filament.

For neutralization by a filament electron-emitter, a DC-AC converter is necessary.

This DC-AC converter has an output power which is a function of the flow of ions to the neutralizer: i.e., of the thrust of the micropropulsor.

The converters mounted on micropropulsors already built have the characteristics given in Table VI.

TABLE VI

Type	V volts	I amps	P watts	Thrust mN
E. O. S.	1.5	2.4	3.6	0.1
H. R. L.	20	0.5	10	2.5

These two micropropulsors have contact ionization. Micropropulsors with /14
bombardment ionization presently use "plasma-bridge" neutralizers (problem of filament life).

III-1-3-2. <u>Neutralization by "Plasma Bridge".</u>

In general, this DC-AC converter is used for heating the cathode and for vaporization of the propellant (see Figure 3.2). [Its characteristics are given in Table VII.]

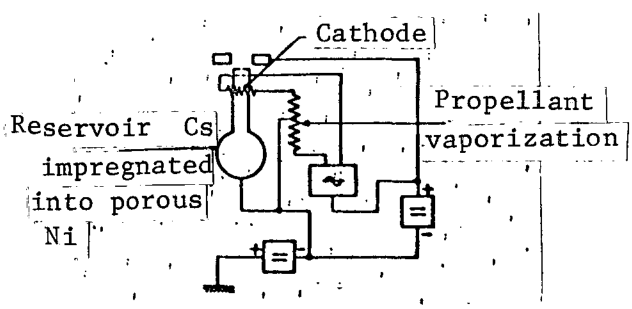

Figure 3.2

The power of this converter represents only a small part of the total power necessary for the micro-propulsor operation. It is naturally a function of the ion current density to be neutralized — that is, the level of micropropulsor power.

III-2. <u>Direct-Current Power Supplies</u>

III-2-1. <u>DC Power Supplies for the Neutralizer ("Plasma-Bridge" Type)</u>

The solution adopted in this case necessitates, as we have just said, two DC-DC converters.

TABLE VII

Type	V volts	I amps	P watts	Thrust mN
Sert II	5.8	1.9	11	30

III-2-1-1. Positive DC Power Supply

It accelerates the electrons and repels the ions leaving. Since the electrons leaving must be at a null potential to avoid deflection of the ion beam, it is necessary to insert a DC-DC converter with negative output (see Figure 3.2).

The parameters of this converter are given in Table VIII for Sert II. /15

TABLE VIII

Type	V volts	I amps	P watts	Thrust mN
Sert II	30	0.23	7	30

This power is naturally a function of the thrust level of the micro-propulsor. In any case, it is always small with respect to the total power required for operation of the latter.

III-2-1-2. Negative DC Power Supply.

The polarity of the converter output is, with respect to the mass, symmetric to that of the preceding converter. The current is given by the sum of the current passing through the positive DC converter and leakage currents in the reservoir.

III-2-2. Positive High Voltage.

According to the study made in Section I-2-1, we need a voltage on the order of several kilovolts. We call this voltage U, and — following our train of reasoning — we shall neglect the beam output voltage. The exhaust velocity of the ions is thus equal to $V=\sqrt{\frac{2e}{m}\times U}$ where m is the mass of the ion, and e is its charge.

If A is the atomic weight of the propellant (in grams per mole), we obtain

$$V = 1.39 \quad 10^4 \frac{\sqrt{U}}{\sqrt{A}}$$

Let F be the required thrust, and N, Avogadro's number. The mass dm of ions ejected during time dt at a velocity V is related to the thrust vector by the relation:

$$F = \frac{dm}{dt} \times V$$

The number of ions ejected during the same time dt is thus: /16

$$dn = \frac{dm\ N}{A} = \frac{F.N.}{V.A.}\,dt,$$

This number equals that of the electrons moved through the positive high voltage. We thus have a charge dQ = dn x e during time dt:

$$dQ = \frac{F}{V} \times \frac{N}{A} \times e\ dt$$

Beam Current I

After all calculations have been made, we obtain for the beam current I:

For mercury:	$I = 490 \dfrac{F}{\sqrt{U}}$
For cesium:	$I = 602 \dfrac{F}{\sqrt{U}}$

Specific Impulse

$$I_{sp} = \frac{V}{g} = \frac{1{,}39\ 10^4 \sqrt{U}}{g \times 31{,}622\sqrt{A}}$$

where A is in kg per mole.

$$I_{sp} = \frac{1{,}39 \times 10^4}{9{,}81 \times 31{,}622} \sqrt{\frac{U}{A}}$$

For mercury:	$I_{sp} = 100.24 \sqrt{U}$
For cesium:	$I_{sp} = 122.8 \sqrt{U}$

Note: For propellant consumption, we would have to introduce the ionization efficiency.

Power P in the Beam /17

For mercury:

$$P = U \times 490 \frac{F}{U}$$

$$P = U \times 490 \times \frac{F \times 100}{I_{sp}}$$

$$\boxed{P = 49\ 000\ U \times \frac{F}{I_{sp}}}$$

For cesium:

$$P = U \times 602 \frac{F}{U}$$

$$P = U \times 602 \times 122,8 \frac{F}{I\,sp}$$

$$\boxed{P = 73\,925 \times U \times \frac{F}{Isp}}$$

The tables and curves of Figures 3.3 through 3.6 have been obtained directly from the preceding formulas.

$U_{(Volts)}$	$F_{(mN)}$	$I\ Hg_{(mA)}$	$I\ Cs_{(mA)}$	$P\ Hg_{(W)}$	$P\ Cs_{(W)}$
1500	3	37, 95	46, 63	59, 92	69, 94
1500	1	12, 65	15, 54	18, 975	23, 31
1500	0, 5	6, 32	7, 77	9, 48	11, 65
2000	3	32, 87	40, 38	65, 74	80, 76
2000	1	10, 96	13, 46	21, 92	26, 92
2000	0, 5	5, 48	6, 73	10, 96	13, 46
2500	3	29, 4	36, 12	73, 5	90,30
2500	1	9, 8	12, 04	24, 5	30, 10
2500	0, 5	4, 9	6, 02	12, 25	15, 05
3000	3	26, 84	32, 97	80, 52	98, 91
3000	1	8, 95	10, 99	26, 85	32, 97
3000	0, 5	4, 47	5, 5	13, 41	16, 5

Figure 3.3
(Decimal points appear as commas)

Table IX shows that the theoretical and experimental values agree well. /18

III-2-3. Negative High Voltage

The voltage of this /19 converter is on the order of one or two kilovolts. The value taken for this voltage is connected to that of the positive high voltage and to the dimensions of the optics. The choice of the two high voltages is a compromise between the specific impulse required for the mission, the efficiency of the micropropulsor, and the life of the accelerating electrode.

The current furnished by this converter is always small compared to that furnished by the positive high voltage converter. It is due to the parasitic

$U_{(volts)}$	F (mN)	I_{sp} Hg (s)	I_{sp} Cs (s)	$\frac{F}{I_{sp}}$ Hg $(10^{-6}$ mN. $s^{-1})$	$\frac{F}{I_{sp}}$ Cs $(10^{-6}$ mN. $s^{-1})$
1500	3	3872	4756	0, 774	0, 630
1500	1	3872	4756	0, 258	0, 210
1500	0, 5	3872	4756	0, 129	0, 105
2000	3	4472	5491	0, 670	0, 546
2000	1	4472	5491	0, 223	0, 182
2000	0, 5	4472	5491	0, 111	0, 091
2500	3	5000	6140	0, 6	0, 489
2500	1	5000	6140	0, 1	0, 081
3000	3	5477	6723	0, 548	0, 446
3000	1	5477	6726	0, 182	0, 149
3000	0, 5	5477	6726	0, 091	0, 074

Figure 3.4
(Decimal points appear as commas.)

TABLE IX

Type	V volts	I mA		P watts		Thrust mN
		Expt.	Calc.	Expt.	Calc.	
Sert I	2500	310	295	775	735	30
Sert II	3000	250	256	750	768	29
E. O. S.	3000	1	1	3	3	0.1
H. R. L.	1700	32	36	54.5	61.2	2.5

currents (chiefly secondary ions with charge exchange). The rather high values found in Table X are explained by the fact that the designers wished to protect

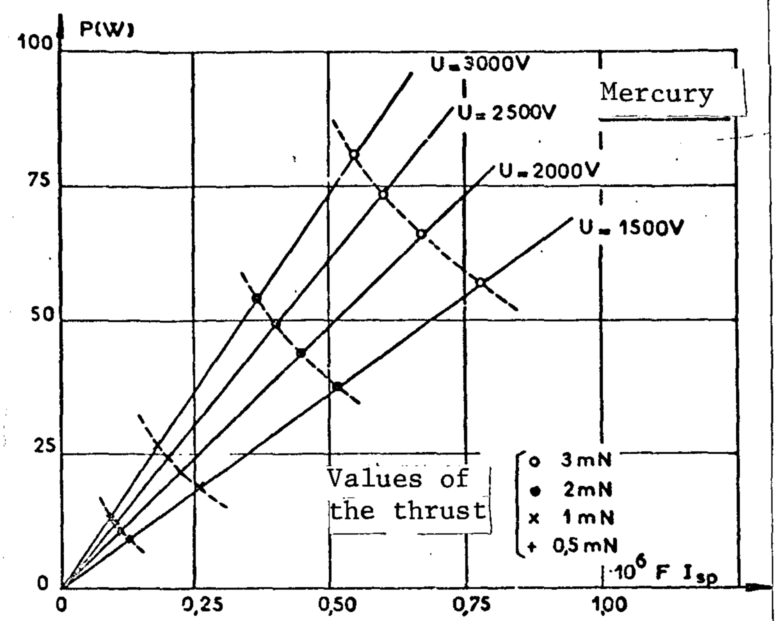

Figure 3.5

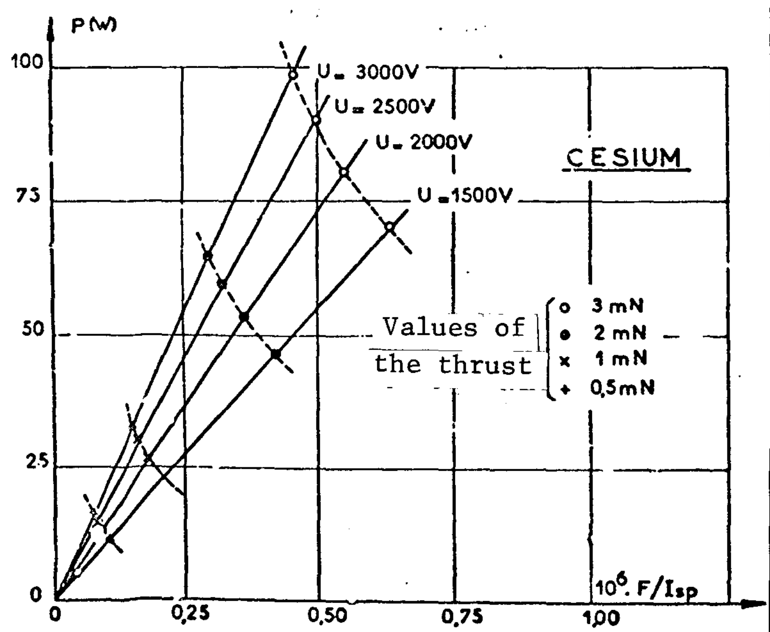

Figure 3.6

the supplies from current spikes due to accidental arcs which might occur during the operation of the micropropulsor.

III-2-4. Logic Power Supply

Definition of this power supply poses no particular problem. The voltages and flows are functions of the elements used in the control logic.

III-2-5. Deflection Power Supply [14], [15], [16]

To obtain the deflection, we need a controllable DC-DC converter.

For a single-strip pro- /20
pulsor, the output voltage must be able to vary from zero to a value determined by the following formula (cf. Section IV-2).

$$\tan \theta_m \simeq \frac{\Delta V_m}{2 V_a} \times \frac{1}{d}$$

TABLE X

Type	V volts	I mA	P watts	Thrust mN
H. R. L.	2000	0.2	0.4	2.5
E. O. S.	2000	< 50 μA	<0.1	0.1
Sert II	1500	1.9	3	30

with Va = V1 — V2, if V1 denotes the positive high voltage, and V2 — the negative high voltage (deflection by accelerating electrode).

1 = length of accelerating electrodes;

d = distance separating accelerating electrodes;

$\frac{\Delta Vm}{2}$ = maximum value of the power supply;

θm = maximum deflection angle imposed.

The current furnished by this power supply is zero at rest (θ=0) and for θm takes a small value on the order of a few tens of milliamperes (parasitic currents due to ion impacts).

IV. CONSTRAINTS ON THE POWER SUPPLIES

IV-1. Alternating-Current Power Supplies.

The AC power required by the micropropulsor serves only for heating. The waveform is not important provided that the effective values of voltage and current are imposed.

IV-1-1. Vaporizer Heating.

As far as we know, this supply requires quite fine regulation for the systems developed up to the present.

IV-1-2. Ionizer Heating.

IV-1-2-1. Heating of Refractory Material.

This power supply needs quite fine regulation, so that the temperature of the material may be fixed in a range from 1150°K to 1350°K.

IV-1-2-2. Heating of Cathode. /21

Fine regulation is necessary for heating the cathode which emits the electrons used for ionization.

IV-1-3. Neutralizer Heating.

The remark made previously still applies; the electrons here serve to neutralize the ion beam.

Current-limiting devices must be designed for all these AC power supplies to avoid high currents due to establishing the total voltage across cold heater assemblies.

IV-2. Direct-Current Power Supplies.

The DC voltages relating to operation of the optics affect the deflection in particular. For a single-strip ion propulsor (Firgure 4.1), we have

$$\tan\theta \approx \frac{\Delta V}{2\,Va} \times \frac{1}{d}$$

where θ is the angle of deflection;

ΔV is the potential difference applied to the electrodes;

Va = value of the accelerating potential;

Va = V1 — V2, if V1 denotes the positive high voltage, and V2 — the negative high voltage;

l = length of accelerating electrodes;

d = distance separating the accelerating electrodes.

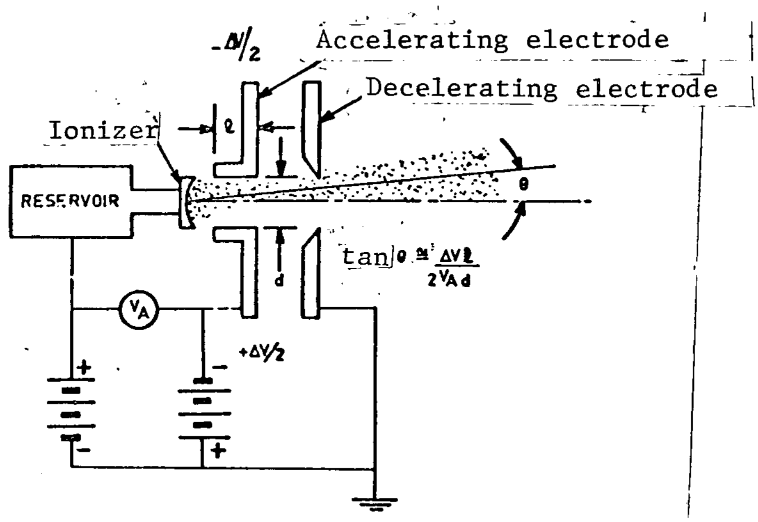

Figure 4.1

The error in θ, for independent quantities and neglecting the error in l and d, is

$$\frac{d\,(\tan\theta)}{(\tan\theta)} = \frac{d\,(\Delta V)}{\Delta V} + \frac{dV1}{V1} + \frac{dV2}{V2}$$

For small angles of deflection, we can approximate tan θ by θ and obtain /22

$$\frac{d\theta}{\theta} = \frac{d\,(\Delta V)}{\Delta V} + \frac{dV1}{V1} + \frac{d\,V2}{V2}$$

For a relative error of 1% in the angle of deflection, and assuming that the relative errors in the voltages are equal, we obtain

$$\frac{d\,(\Delta V)}{\Delta V} = \frac{d\,V1}{V1} = \frac{dV2}{V2} \simeq \frac{3}{1000}$$

According to the type of converter used, the ripple frequency is equal to the operating frequency or twice that value. This operating frequency is generally on the order of ten kilohertz. Since the beam has a response time on the order of microseconds, we must then include in the relative error the regulation coefficient, and also the ripple rate.

These two parameters must be determined for each DC power supply, so that the sum of the three relative errors never exceeds a certain value which we have taken equal to 1%.

NOTE

For technological reasons (operational life of the optics and of the neutralizer), the angle of deflection is presently on the order of ± 10° for operational micropropulsors. Studies in progress have, however, allowed greater deflection angles to be obtained (± 18° for propulsors effectively built, and ± 30° for systems studied in the laboratory).

V. DETERMINATION OF THE POWER-CONVERTER SUBSYSTEM FOR THE MICROPROPULSOR PRESENTLY PROPOSED BY THE NATIONAL CENTER FOR SPACE STUDIES (C. N. E. S.) (Subject of basic research). /23

The ion micropropulsor, for which we are going to determine the power-converter subsystem, has the following characteristics:

- Type: Single-strip propulsor with contact ionization of cesium and electrostatic beam deflection.

- Thrust: no modulation possible; a value between 0.5 and 3 mN.

- Electrical consumption: from 50 to 70 W/mN, or from 35 to 200 W total.

- Specific impulse: around 5000 s.

- Beam current density: around 6 mA/cm^2.

- Beam deflection: minimum amplitude of 10° on one side and the other of the axis.

- Useful power: at least 99%.

- Overall efficiency: about 35%.

- Operating life: 12 hours per day for five years, or about 22,000 hr.

V-1. Alternating-Current Power Supplies

The studies made in Chapter III allow:

- the necessary AC power to be determined (Table XI).

- voltage-current characteristics to be proposed (Table XII). /24

The characteristics of these AC power supplies are those given in Chapter IV.

TABLE XI

F_{mN}	Ionizer Power (watts)	Vaporizer Power (watts)	Neutralizer Power (watts)
0.5	17	3.5	1.5
3	70	4.3	3

V-2. Direct-Current Power Supplies.

V-2-1. Positive High Voltage Power Supply.

For cesium, we have seen that the specific impulse is given by

$$I_{sp} = 122.8 \sqrt{U}.$$

For I_{sp} = 5000 s, one obtains U = 1657 V. We shall take U = 2000 V, which will in fact give a specific impulse of 5492 s.

TABLE XII a.

F = 0.5 mN	V volts	I amps	P watts
Ionizer	10	1.7	17
Vaporizer	3.5	1	3.5
Neutralizer	3	0.5	1.5

TABLE XII b.

F - 3 mN	V volts	I amps	P watts
Ionizer	30	2,7	80
Vaporizer	4.5	1	4.5
Neutralizer	3	1	3

The current I furnished by this power supply is given by $I = 602 \frac{F}{\sqrt{U}}$, or I = 13,461 F.

The values of the current furnished and this power supply are given by the curves of Figure 5.1. /25

V-2-2. Negative High-Voltage Power Supply.

A negative high voltage on the order of 1000 to 1500 V will be taken. The current furnished will be on the order of a few μA for thrusts of 0.5 to 3 mN.

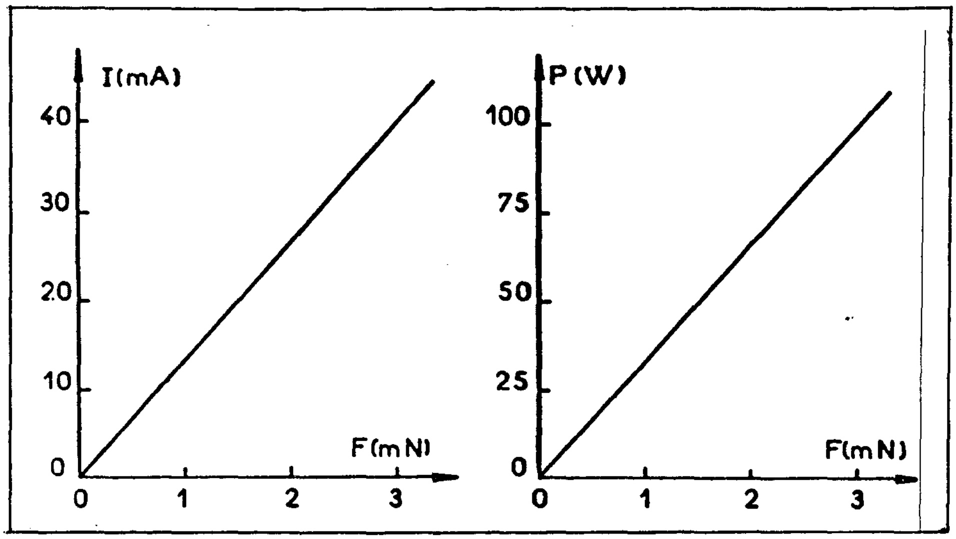

Figure 5.1

V-2-3. Direct-Current Power Supply with Controllable Output.

For a single-slit propulsor, we can write (see Section IV-2):

$$\tan\theta = \frac{\Delta V}{2Va}\,\frac{1}{d}$$

For a negative high voltage of 1500 V and a maximum deflection angle of 10°, one has Va = 2000 — (—1500) = 3500 V, and $\tan 10° = \frac{\Delta V}{2} \times \frac{1}{3500} \times \frac{1}{d}$.

$$\frac{\Delta V}{2} = 616 \times \frac{d}{1}$$

We must thus have a DC power supply whose output must vary from 0 to $\Delta V/2$ volts.

The current furnished is always very small (a few tens of μA). For all these positive supplies, the constraints are those given in Chapter IV.

Power supply	Type	V	I	P watts
Ionizer	AC	10 V	1.7 A	17
Vaporizer	AC	3.5 V	1 A	3.5
Neutralizer	AC	3 V	0.5 A	1.5
HV > 0	DC	2000 V	6.7 mA	13.5
HV < 0	DC	1500 V	0.5 mA	0.75
Variable output	Controlled DC	0 — 200 V	0 — 50 μA	$\cong$ 0
Total Power				36.25

Figure 5.2

Power Supply	Type	V	I	P watts
Ionizer	AC	30 V	2.7 A	80
Vaporizer	AC	4.5 V	1 A	4.5
Neutralizer	AC	3 V	1 A	3
HV > 0	DC	2000 V	40 mA	81
HV < 0	DC	-1500 V	5 mA	7.5
Variable output	Controlled DC	0 — 200 V	0 — 100 μA	0
Total Power				170

Figure 5.3

V-3. Recapitulatory Tables.

The two tables of Figures 5.2 and 5.3 give the characteristics of the power supplies for the two micropropulsors using contact ionization of cesium, with 0.5 mN and 3 mN thrusts, respectively.

The curves of Figure 5.4 give the total power and the two principal powers as functions of the thrust.

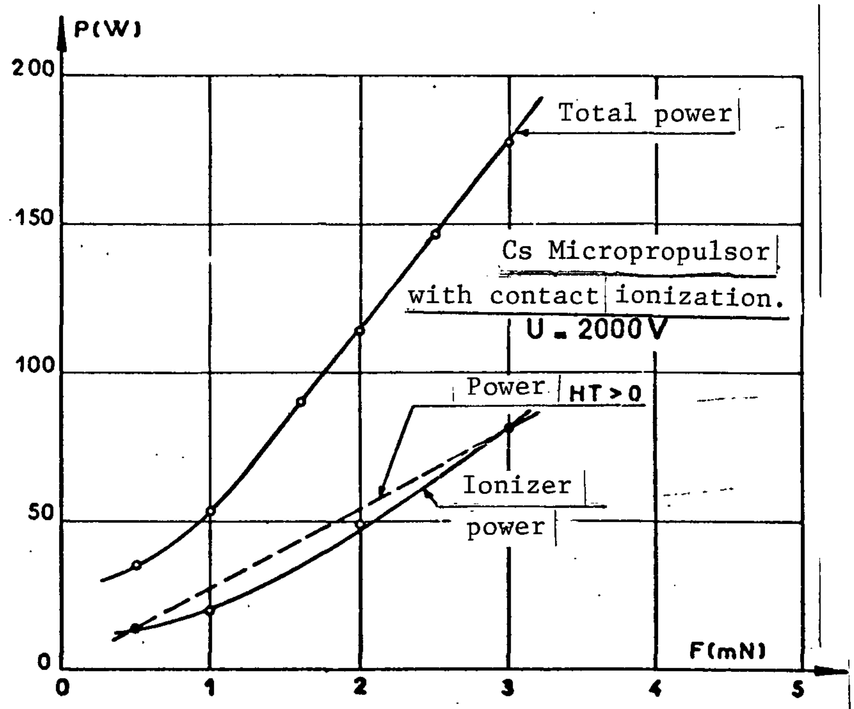

Figure 5.4

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